## 1. INTRODUCTION

The title in the top margin of this document perhaps suggests that the 4-Bed Carbon Dioxide Removal equipment was only operating on the date shown, however, as life support equipment, this technology is used on and off around the clock on the International Space Station (ISS). It is a mainstay for metabolic carbon dioxide ($CO_2$) removal and crew life support. The previous generation was known as the Carbon Dioxide Removal Assembly (CDRA) with a long history of unplanned maintenance as well as obsolete core components. The 4-Bed $CO_2$ equipment was commissioned to operate with no unplanned maintenance for 3 years while removing 4 crew-equivalents of $CO_2$ at a target inlet concentration of 2 torr $CO_2$.

Starting at about GMT 2022-12-03, 3337/12:16, two NASA astronauts conducted an Extravehicular Activity (EVA) or spacewalk outside the International Space Station (ISS) that would last just over 7 hours. Assisted by Canadarm 2, Josh Cassada and Frank Rubio installed an ISS Roll-Out Solar Array (iROSA) for use with the 3A power channel on the starboard truss of the ISS. This installation marked the third such iROSA to be attached to the space station since a power augmentation program to add at least six new sets of arrays to the ISS began in 2021. A subsequent EVA to install a fourth iROSA, this time to the 4A power channel on the port truss of the ISS, is currently scheduled for later in December of 2022. See Figure **??** for an artistic rendering of the iROSAs – 3 outlined in magenta.

The spacewalkers undid bolts and installed cables and at GMT 17:37, the array was deployed to start tapping into the Sun's radiation to generate electrical power. As part of get-ahead tasks, they prepared the 4A array for the next spacewalk, demated the 1B array, broke torque on the P4 electronic boxes, and installed cables along the truss to be mated at the end of EVA 4. This spacewalk faced a delay when Cassada's suit did not power up initially. Troubleshooting steps were done and power was restored to Cassada's suit.

The iROSAs are part of a plan by NASA to increase the ISS's power generation capability back to what it essentially was when the eight original solar array wings were launched between 2000 and 2009. With the placement of six iROSAs on the station, the orbital lab will once again be capable of producing 215 kW of power for its scientific and operational needs. The original arrays, as expected, degraded in efficiency over time and are now only capable of generating approximately 160 kW. Each new iROSA will contribute approximately 10 kW of power to the ISS.

For the microgravity acceleraiton environment analysis using Space Acceleration Measurement System (SAMS) data in this document, we consider the hour subset from GMT 13:00 to 19:00 for a few days leading up to the EVA, the day of the EVA, and a few days after the EVA to give some comparison context.

## 2. QUALIFY

The spectrogram of Figure 2 on page 4 was calculated from SAMS sensor 121f08 acceleration measurements made in the Columbus module. This plot focuses on a lower-frequency portion of the acceleration spectrum usually dominated by vehicle structural modes and crew activity such as exercise, or in this case push-offs, torques, and landings by the crew on external structures of the ISS during the EVA. This plot includes a white annotation (that is probably not needed) to show the impact mainly below 2 Hz, where large structures' natural flexing/bending/twisting modes tend to dominate the vibratory regime. We see clearly in the spectrogram from about GMT 10:54 to about 19:17 that the large structures of the ISS were moving and vibrating more energetically as they were impinged by the crew's locomotion and activity. This shows up as horizontal streaks that turn red (more energetic) during the EVA compared to yellow (less energetic) before and after the EVA.

## 3. QUANTIFY

In order to quantify the impact of the EVA, we will focus our attention below 6 Hz and show statistical summaries over several days from a relatively large volume of SAMS measurements in that span. We will consider 5 SAMS sensor heads distributed throughout the space station and compare and contrast across sensor locations and also compare results below 6 Hz to corresponding measurements up to 200 Hz.

Before we present those statistical results, we outline and describe the signal processing chain in order to provide the foundation for our analysis.

The signal processing steps for each day considered were as follows:

1) read entire day of data into 2d array; 4 columns: time, x-, y-, & z-axis accel.
2) keep only rows where time is between GMT 13:00 and 19:00; discard the rest
3) compute per-axis 5-stat summary: 1st, 25th, 50th, 75th, & 99th percentiles
4) subtract off median value (50th percentile) on per-axis basis

5) boxplot the percentiles as depicted in Figure **??** on per-axis, per-day basis for the hours of interest; with a boxplot for each of **red** = x-axis, **green** = y-axis, and **blue** = z-axis results

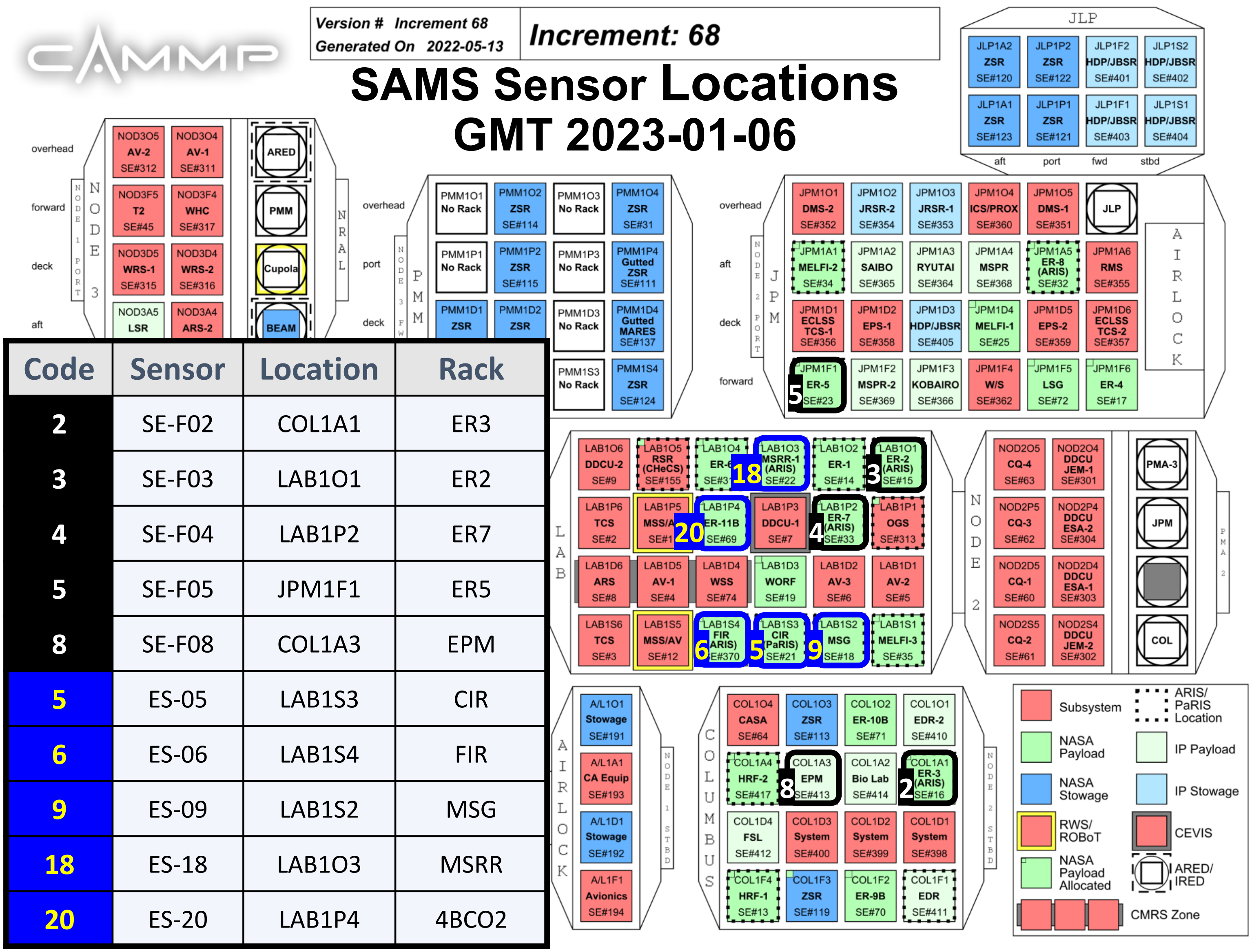
## 4. CONCLUSION

The analysis results from 5 SAMS sensor heads distributed across all 3 main labs of the ISS over 9 days centered on the day of the EVA and for the hours in the span from GMT 13:00 to 19:00 each day are shown for:

- 6 Hz data sets (*micro-g scale*) in Figures **??** through **??** (pages **??** through **??**)
- 200 Hz data sets (*milli-g scale*) in Figures **??** through **??** (pages **??** through **??**)

**The spectrogram in Figure 2 along with the boxplot results in Figures ?? through ?? show the following notable features**:

- despite showing statistical results below 6 Hz, it is clear from our spectral analysis the main impact of this EVA was concentrated below 2 Hz (for convenience, we tapped into pre-existing 6 Hz data sets)
- results below 6 Hz show obvious Z-axis acceleration correlation: we see "strong Z-axis vibe magnitudes" on the EVA day versus "less Z-axis vibe magnitudes" on the non-EVA days considering the span from GMT 13:00 to 19:00
- results below 200 Hz also embody vibrations below 6 Hz, but we do not see obvious correlation for the higher-frequency data (as expected) since the primary impact of crew activity such as this (and, in general) lies in the lower-frequency vibratory regime whereas higher-frequency vibrations are more localized, are typically coming from equipment operations nearby the sensor head being considered, and these higher-frequency vibrations dominate (overwhelm) the sub-6 Hz, lower-magnitude vibrations
- the very large magnitude, higher-frequency vibrations manifest in SAMS 121f03 data, primarily aligned with the Z-axis (see Figure **??**) were attributable to a narrowband disturbance near 60 Hz most likely from equipment in ER-2 (LAB1O1) – we see that strong 60 Hz disturbance start as depicted in the 7-day, early November statistical plot of Figure **??** and the two Principal Component Spectral Analysis (PCSA) plots in Figure **??** and **??**.




| Code | Sensor | Location | Rack |
|---|---|---|---|
| 2 | SE-F02 | COL1A1 | ER3 |
| 3 | SE-F03 | LAB1O1 | ER2 |
| 4 | SE-F04 | LAB1P2 | ER7 |
| 5 | SE-F05 | JPM1F1 | ER5 |
| 8 | SE-F08 | COL1A3 | EPM |
| 5 | ES-05 | LAB1S3 | CIR |
| 6 | ES-06 | LAB1S4 | FIR |
| 9 | ES-09 | LAB1S2 | MSG |
| 18 | ES-18 | LAB1O3 | MSRR |
| 20 | ES-20 | LAB1P4 | 4BCO2 |

Fig. 1: ISS Topology showing **SAMS Sensor Locations** on GMT 2023-01-06.

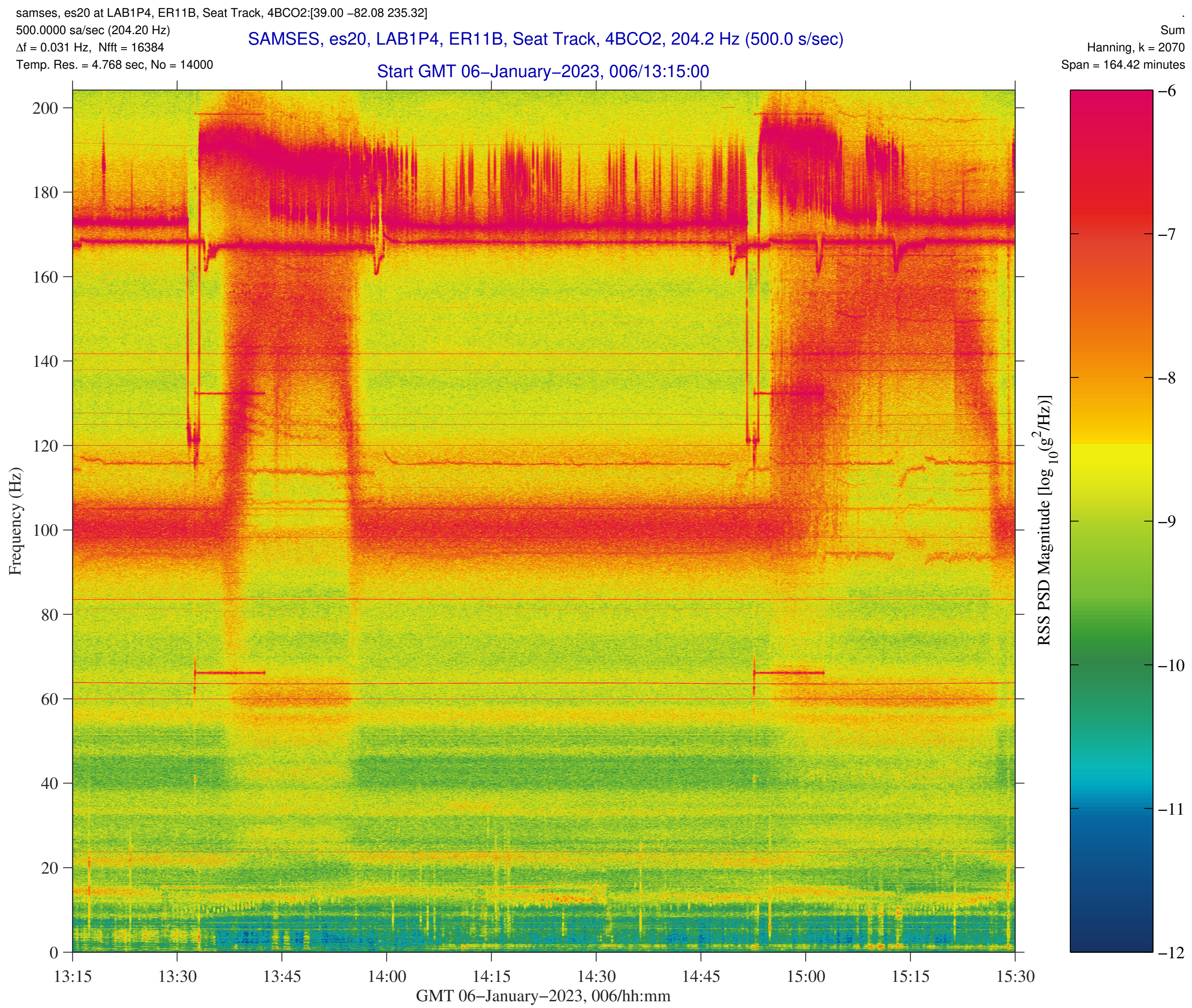



Fig. 2: ~Two-Hour Spectrogram (< 200 Hz) SAMS Sensor es20 on GMT 2023-01-06.

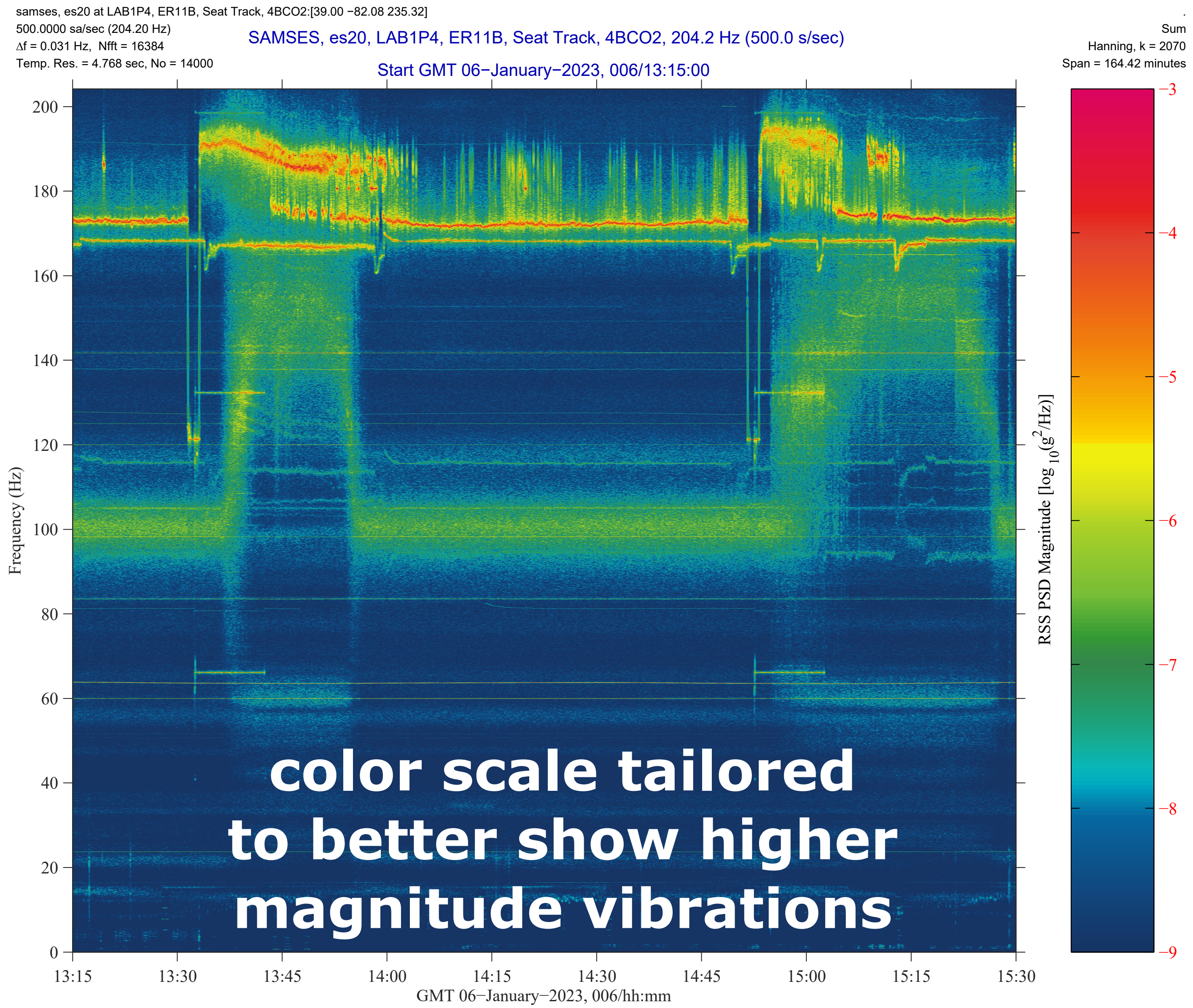



Fig. 3: Replot Previous Spectrogram with **Tailored Color Scale** to Better Show 4BCO2 Signatures.

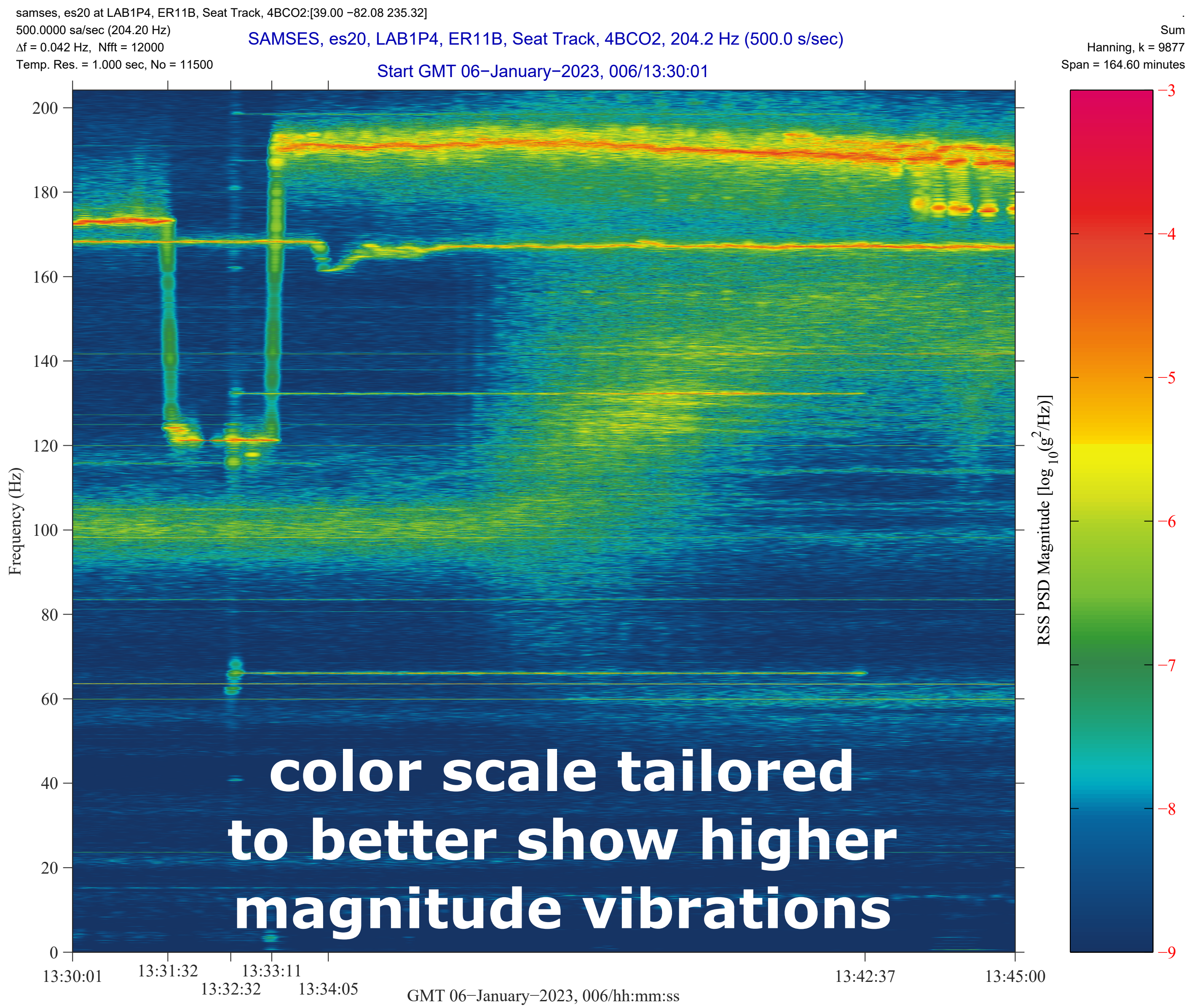



Fig. 4: **15-Minute Zoom-In** of Previous Spectrogram.

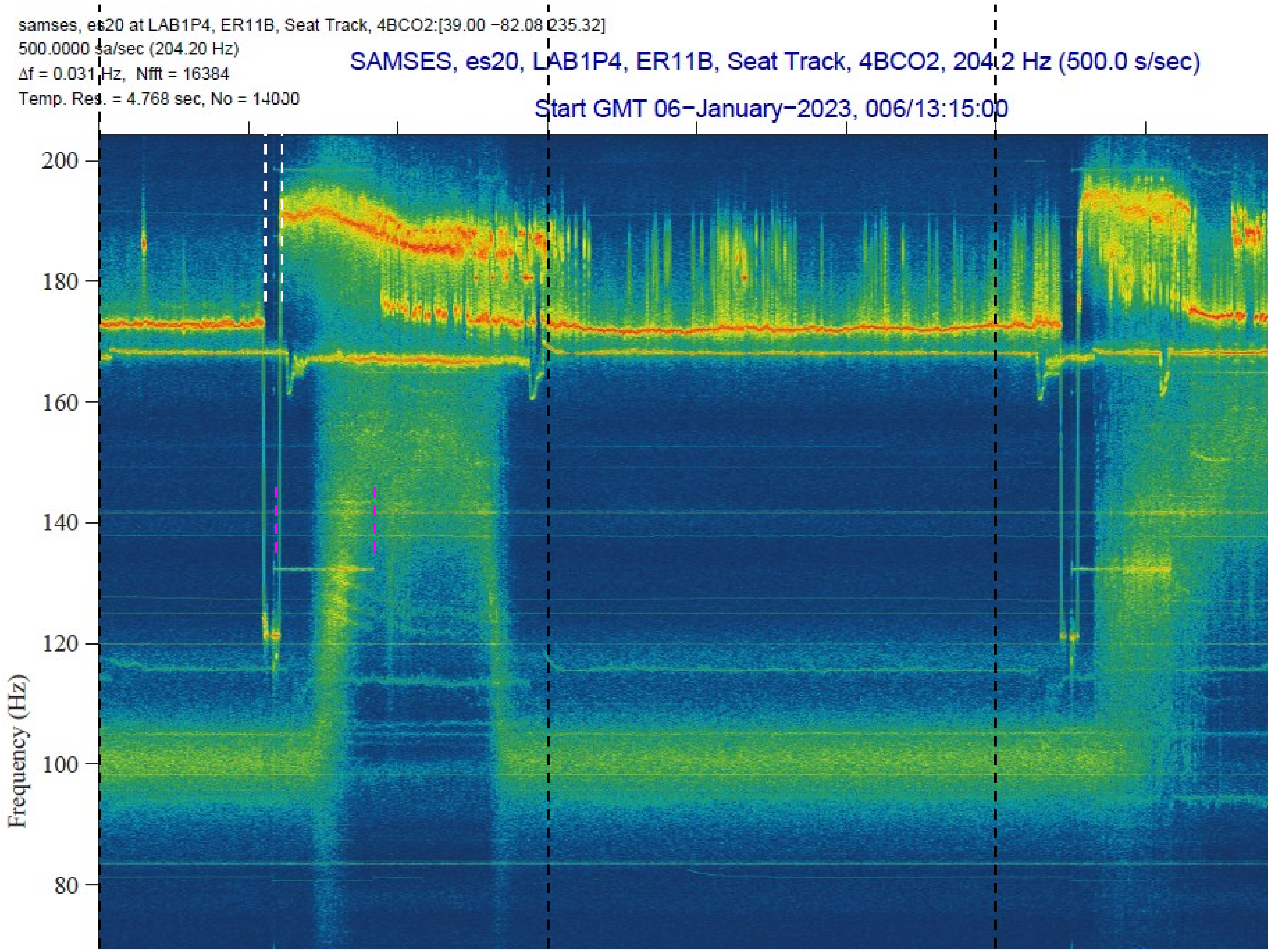



Fig. 5: Overlay #1 (*use your PDF viewer/alignment skills to toggle back/forth with next page*).

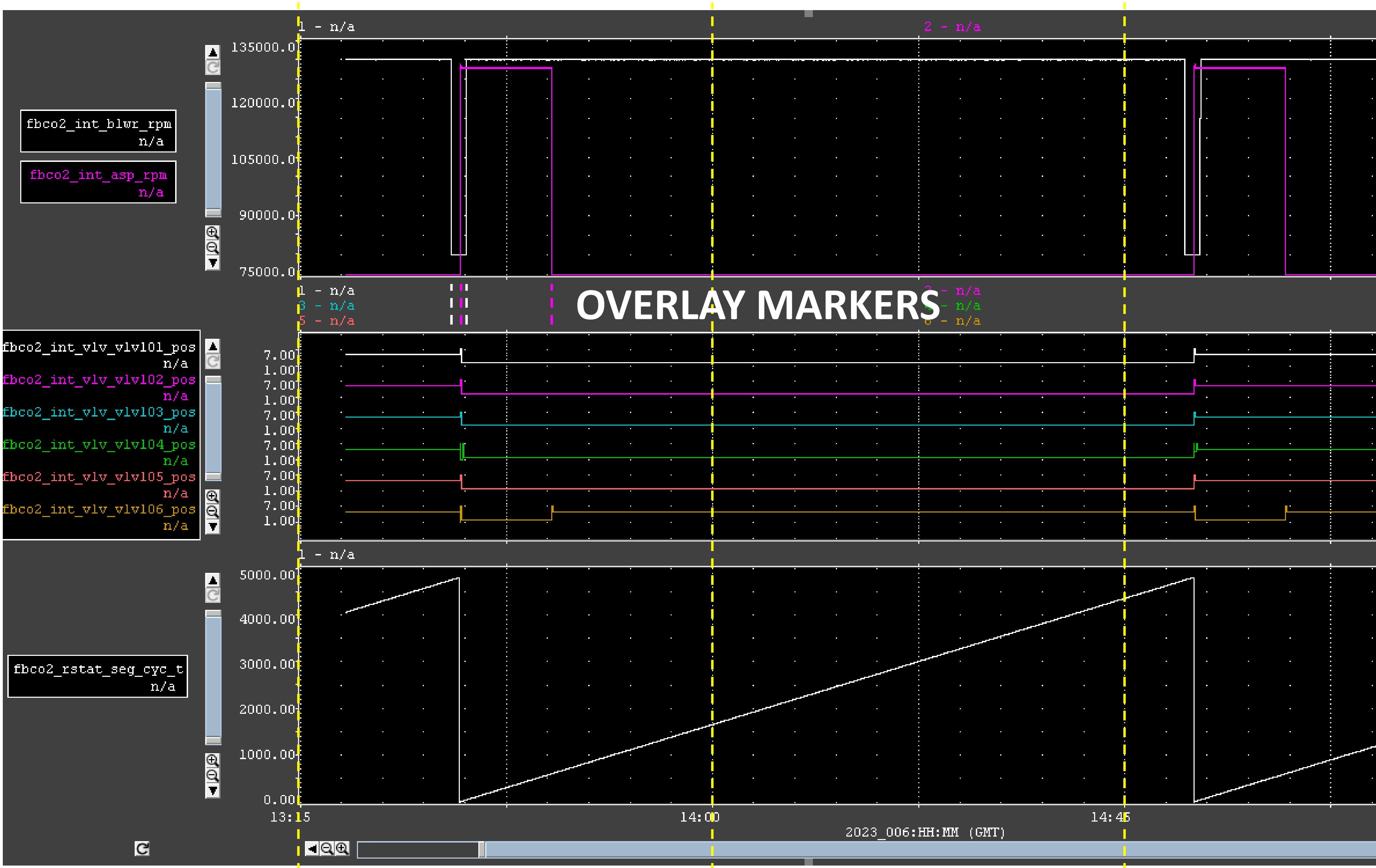



Fig. 6: Overlay #2 (*use your PDF viewer/alignment skills to toggle back/forth with previous page*).

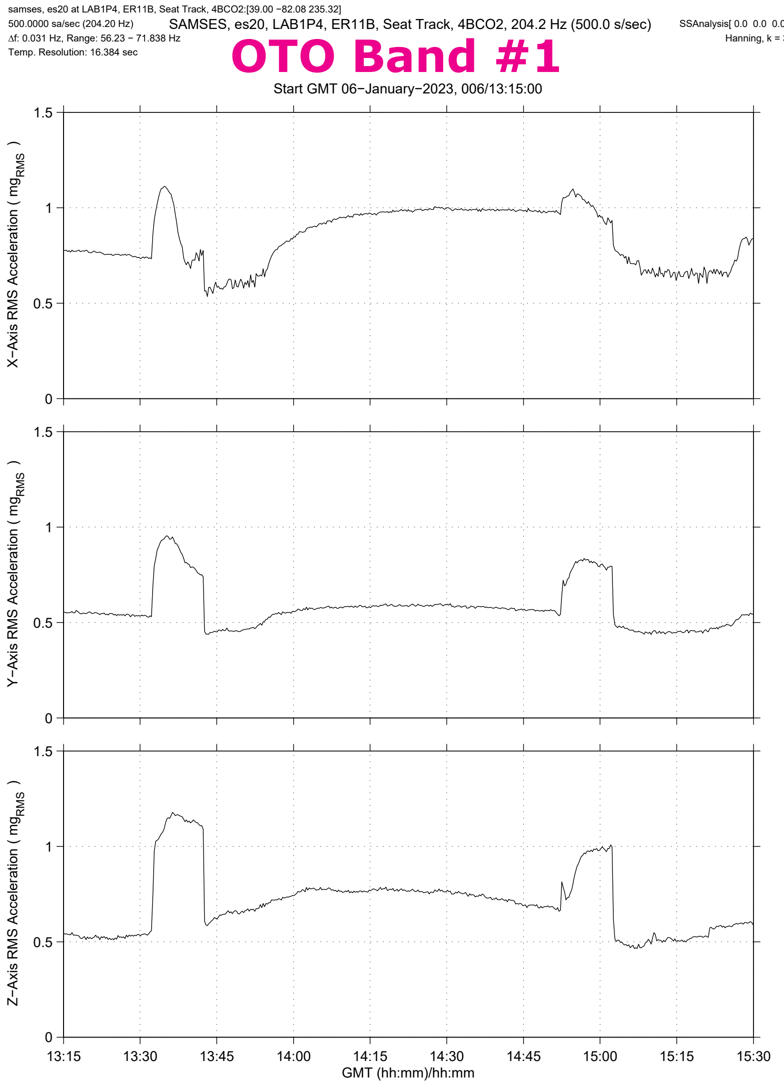



Fig. 7: 16-sec Interval RMS Acceleration **(56 < f < 72 Hz)**.

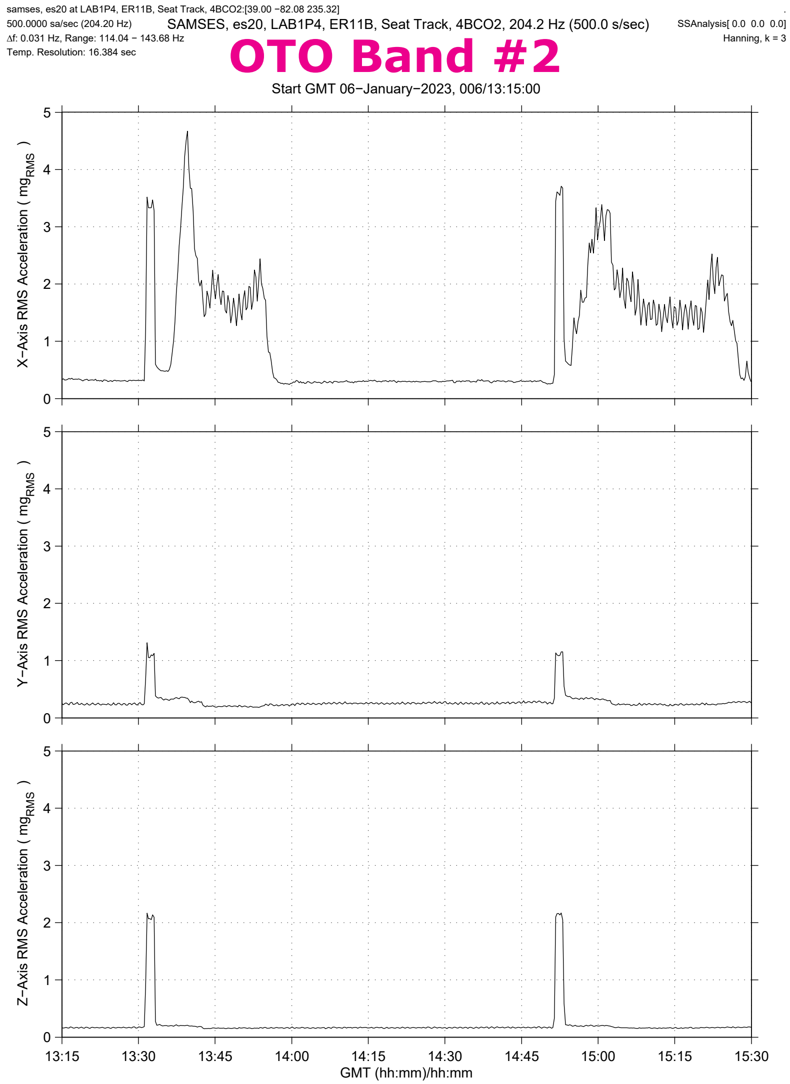



Fig. 8: 16-sec Interval RMS Acceleration **(114 < f < 144 Hz)**.

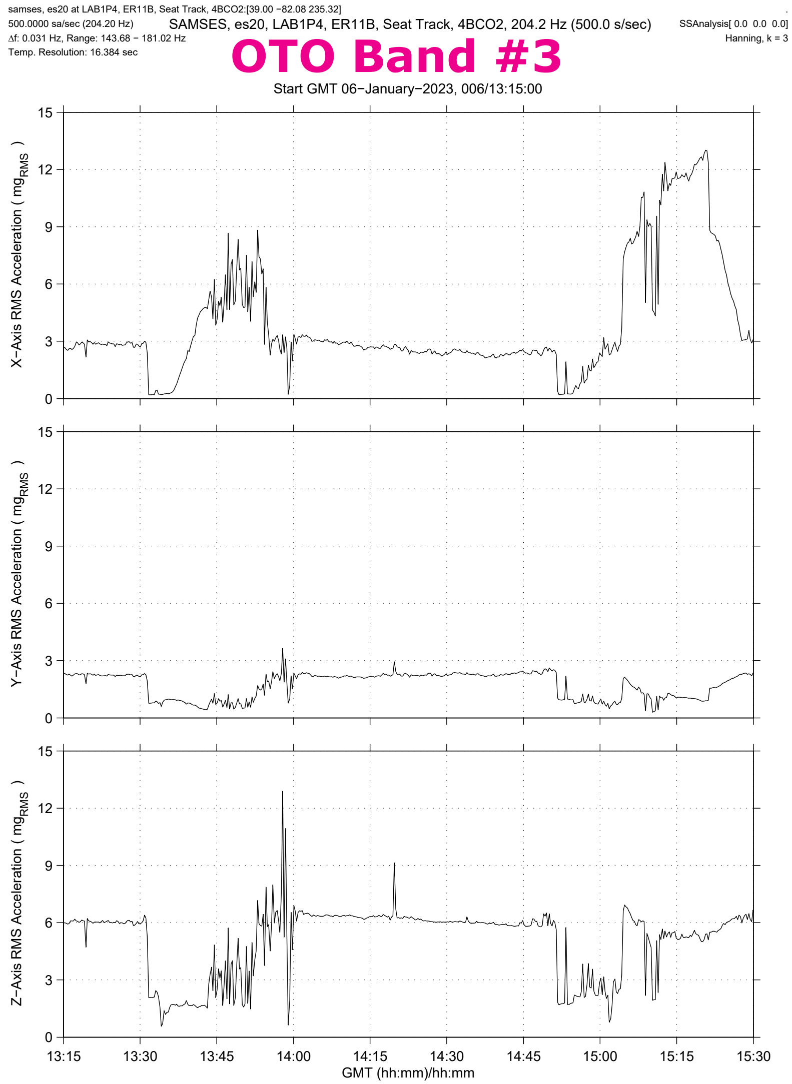



Fig. 9: 16-sec Interval RMS Acceleration **(144 < f < 181 Hz)**.

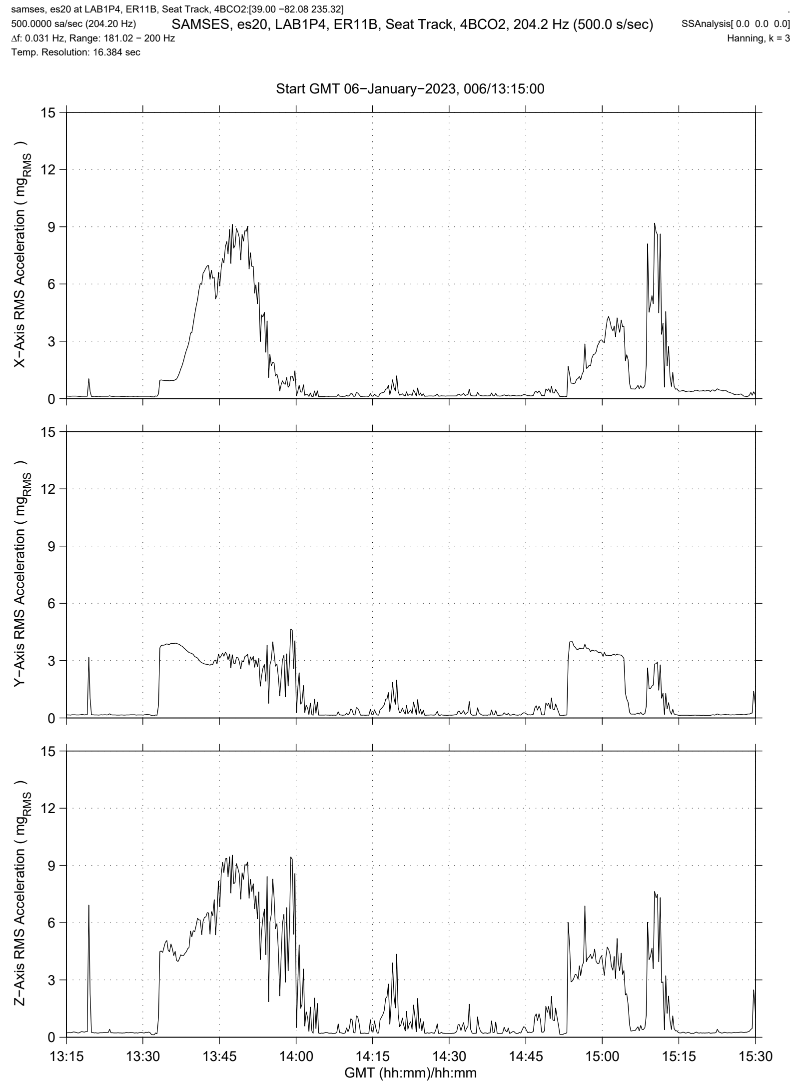



Fig. 10: 16-sec Interval RMS Acceleration **(181 < f < 200 Hz)**.

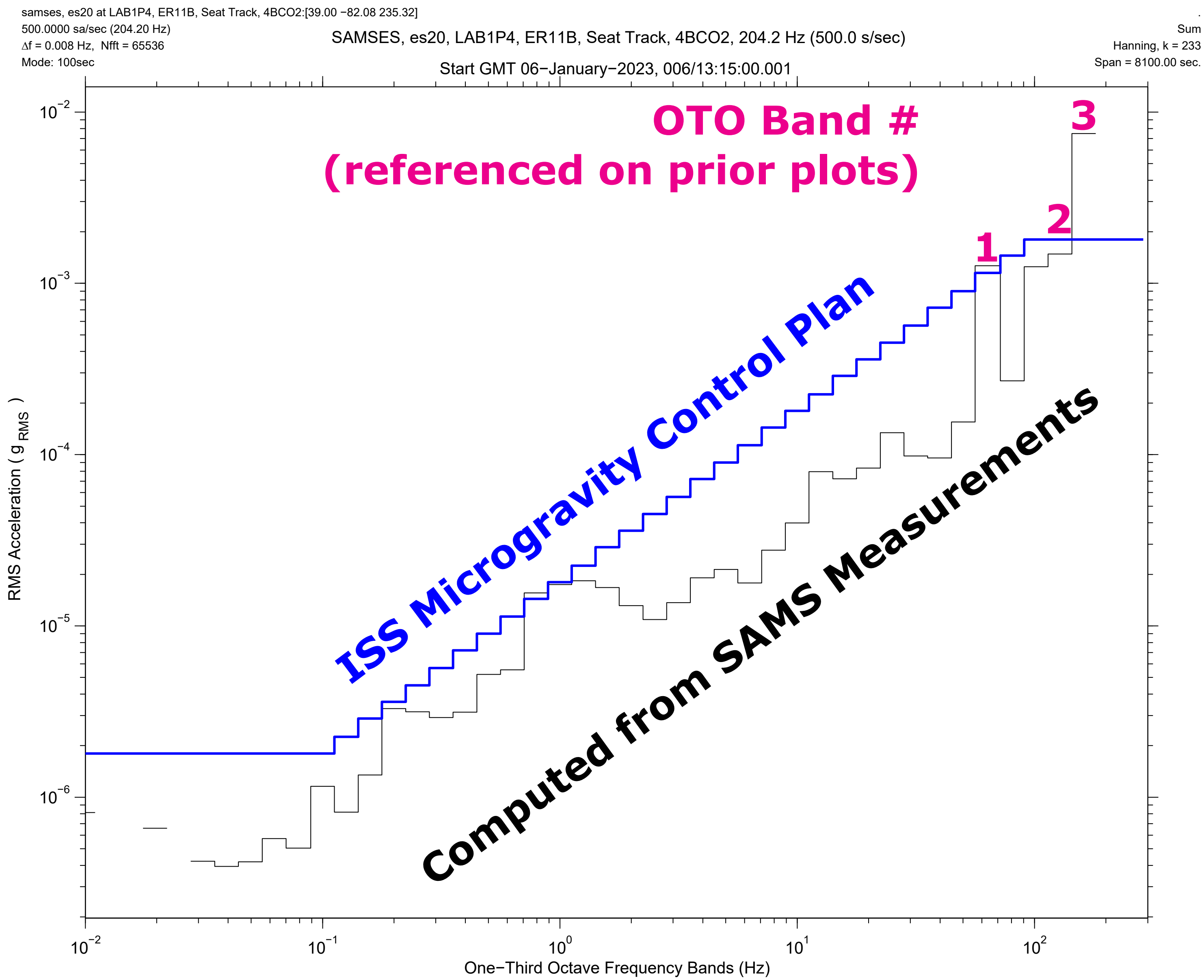



Fig. 11: RMS Acceleration versus One-Third Octave (OTO) Frequency Band.